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DEPENDENCE OF PROPELLER EFFICIENCY ON ANGLE OF ATTACK OF
PROPELLER BLADE.

By

Hermann Borck.

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DEPENDENCE OF PROPELLER EFFICIENCY ON ANGLE OF ATTACK OF
PROPELLER BLADE.*

By

Hermann Böck.

In order to determine the maximum and the most favorable pitch for propeller, it was found desirable to investigate the dependence of propeller efficiency on the angle of attack of the propeller blades.

For lack of space, I will here give briefly the results of only a few experiments, which will, however, suffice to show that propeller blades conduct themselves just like airplane wings with reference to the dependence of their efficiency on their angle of attack.

I will first give a few explanatory remarks to facilitate the understanding of what follows.

The value of the angle of attack is taken at a distance of 0.75 r from the propeller axis.

The forward propeller velocity v_{pr} is calculated according to the formula

$$v_{pr} = \frac{v_F l}{\eta'}$$

in which

$$\eta' = \frac{2}{1 + \sqrt{1 + \frac{2g}{\gamma} \cdot \frac{1}{v_{Fl}} \cdot \frac{S}{F}}}$$

* From "Zeitschrift für Flugtechnik und Motorluftschiffahrt,"
November 15, 1920, pp. 313-314.

is the efficiency due to the slip.

For the stationary test, the formula is simplified to

$$v_{pr} = \sqrt{\frac{g S}{2 \gamma F}}$$

In the above formulas

- g is acceleration due to gravity,
- γ is weight of 1 cu.m. of air in kg.,
- S is thrust measured in kg.,
- F is propeller disk in sq.m.,
- v_F is flight speed with reference to the air.

In order to be independent of the propeller slip, the total efficiency is divided by the slip efficiency, and thus the mechanical efficiency of the propeller is determined with relation to angle of attack. (See Börck, "Zeitschrift für Schiffbau," 1919, Vol. XX, pp. 161 and 199.)

For the practical propellers under consideration, there would have been no object in carrying the analysis of engine efficiency further.

The experimental results rest on:

1. Experiments by the writer at the "Flugzeugmeisterei" (Technical Section of the Air Service);
2. Experiments performed by Dr. Schaffran with air propeller models in the water at the institute for hydrodynamics and ship building, under orders of the inspector of the air forces.
3. Experiments with an "Eta" propeller on the propeller testing stand at Fischamend near Vienna, the results of which were placed at my disposal by the Eta propeller factory.

Experiment 1. Nine propellers of 2.8 m. diameter, 0.2 m. width, and respective pitches of 0.0, 0.56, 1.12, 1.68, 2.24, 2.8, 3.36, 4.48, and 5.6 m. were tested on the electric testing stand at 800 r.p.m., and their thrust and torque measured. The results are given in

Table 1.

Experiment No.	Geom. pitch: m.	Torque: kgm.	Thrust: kg.	Revolution: per sec.	Engine Power: kgm/s	Mechanical Efficiency: η	Angle of attack
1	0.00:	2.4:	24	13.3	201	0.49	0°
2	0.56:	8.2:	71	"	687	0.71	3°
3	1.12:	17.5:	118	"	1464	0.71	6.7°
4	1.68:	28.5:	163	"	2390	0.71	10.5°
5	2.24:	41.0:	203	"	3430	0.68	14°
6	2.80:	64.7:	196	"	5420	0.41	18°
7	3.36:	81.7:	208	"	6850	0.35	22°
8	4.48:	108.4:	233	"	9080	0.32	29°
9	5.60:	130.0:	215	"	10900	0.23	35°

The determination of the effective pitch gave a value about 3% above the geometrical pitch. The result of No. 1 can make no claim to sufficient accuracy, since the experimental errors in the measurement of the torque and thrust are too great in relation to the measured values.

Experiment 2. A two-bladed propeller model (diameter 120 mm., width of blade 9 mm., geometrical pitch 96 mm., effective pitch 104 mm.) was tested in water at different flight speeds and a revolution speed of 30 per second. The results are given in Table 2.

Table 3.

Speed	:	Torque	:	Thrust	:	Mechanical	:	Angle of
m/sec.	:	kgm.	:	kg.	:	Efficiency	:	attack.
	:		:		:	η	:	
0.00	:	0.031	:	3.03	:	0.59	:	13.1°
0.36	:	0.031	:	2.92	:	0.63	:	11.1°
0.72	:	0.031	:	2.77	:	0.71	:	9.8°
1.08	:	0.031	:	2.60	:	0.77	:	8.2°
1.44	:	0.030	:	2.30	:	0.80	:	7.0°
1.80	:	0.029	:	1.95	:	0.82	:	5.7°
2.16	:	0.025	:	1.52	:	0.78	:	4.2°
2.52	:	0.020	:	1.03	:	0.74	:	2.5°
2.88	:	0.012	:	0.44	:	0.59	:	1.0°

Experiment 3. An Eta propeller (diameter 2.8 m., width of blade 0.215 m., geometrical pitch 2.1 m., effective pitch about 2.4 m.) was tested at various revolution speeds, from 1000 to 1400 r.p.m., and at various air velocities on the testing stand in the propeller testing laboratory at Fischamend. Only the final results of the experiment are given in Table 3, since it would carry me beyond the scope of this article to repeat the complicated calculations.

Table 3.

Mechanical efficiency, η	:	0.87	:	0.86	:	0.85	:	0.64
Angle of attack, degrees	:	2.3	:	4.1	:	6.2	:	13.3

Fig. 1 shows the results of the three experiments in the form of curves representing the mechanical efficiency with relation to the angle of attack α . The curves show that the maximum mechanical propeller efficiency lies at about 5°, the same angle at which a wing has the greatest efficiency. Curve 3 has

a somewhat different character from curves 1 and 2, which is probably due to experimental errors.

It is interesting to note in curve 1 the sudden drop in efficiency between 14° and 18° , which again shows the analogy between propeller blades and wings.

The practical conclusion from these experiments is that the propeller pitch should be such that it will work under the various flight conditions with attacking angles of 3° to 6° , a condition which is almost universally fulfilled by propellers now in use.

Supplement.

If we convert the conceptions defined for the propeller into speed and angle values, which occur in the wings of an airplane in flight, we can obtain more accurate definitions of these quantities.

The value for a wing, corresponding to the effective pitch of a propeller, is then in the same direction in which the wing must stand for the lift to be 0 and which we will call the direction of the effective wing. The following values are given in Fig. 2:

- v_1 Climbing speed of airplane;
- v_2 Velocity with which the air flows through the projection of the surface swept by the wings in the unit of time. The corresponding values in the propeller slip stream are the forward speed of the propeller and the speed in the propeller disk;
- v_3 Maximum vertical downward speed of the air, corresponding to the maximum speed of the slip stream;

v_4 Horizontal speed;

v_5 True relative speed of the wing to the air

$$= \sqrt{v_2^2 + v_4^2};$$

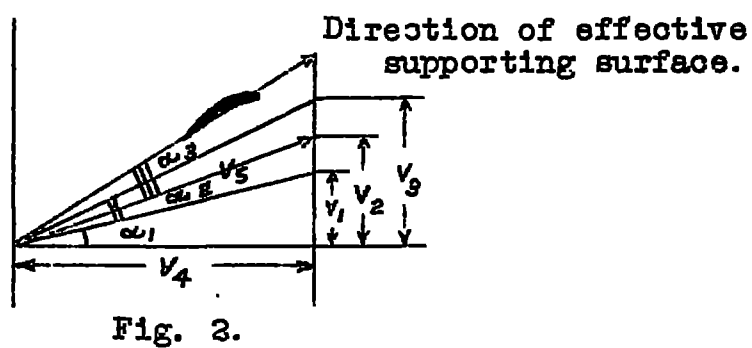
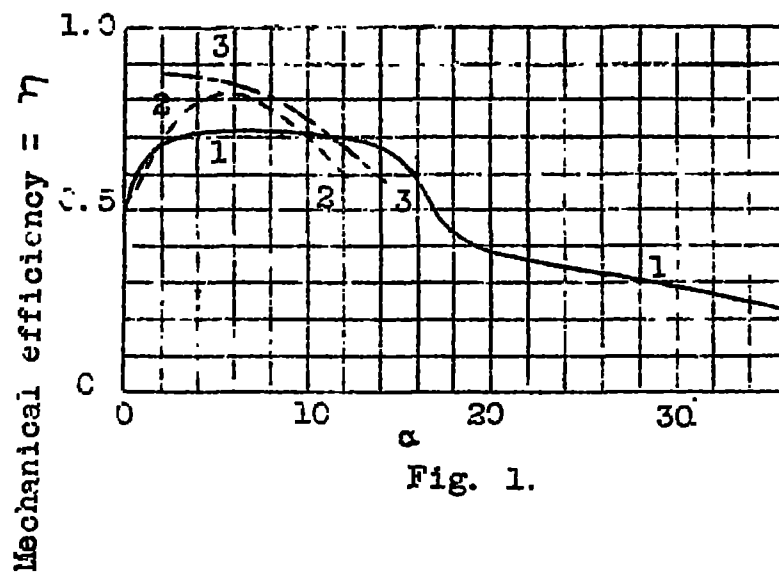
α_1 Angle of attack of airplane with reference to the earth;

α_2 Angle of deflection of air filaments;

α_3 Effective angle of attack.

The different speeds can be calculated by the same formulas as for the propeller, whereby the total weight of the airplane corresponds to the propeller thrust.

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